Agricultural Water Management 96 (2009) 912–916

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

Subsurface drip irrigation of corn in the United States Mid-South

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ARTICLE INFO

Article history:
Received 19 February 2008
Accepted 6 December 2008
Available online 21 January 2009

Keywords:
SDI
Maize
Water management
Crop management

ABSTRACT

Although rainfall in the United States Mid-South is sufficient to produce corn (*Zea mays* L.) without irrigation in most years, timely irrigation has been shown to increase yields. The recent interest in ethanol fuels is expected to lead to increases in US corn production, and subsurface drip irrigation (SDI) is one possible way to increase application efficiency and thereby reduce water use. The objective of this study was to determine the response of SDI-irrigated corn produced in the US Mid-South. Field studies were conducted at the University of Arkansas Northeast Research and Extension Center at Keiser during the 2002–2004 growing seasons. The soil was mixed, with areas of fine sandy loam, loamy sand, and silty clay. SDI tubing was placed under every row at a depth of approximately 30 cm. Three irrigation levels were compared, with irrigation replacing 100% and 60% of estimated daily water use and no irrigations. The split plot treatment was hybrid, with three hybrids of different relative maturities. Although the 3-year means indicated significantly lower yields for a nonirrigated treatment, no significant differences were observed among the treatments in 2003 or 2004. A large difference was observed in 2002, the year with the least rainfall during the study period, but no difference was detected between the two irrigated treatments in any year. The treatment with the lower water application had the higher irrigation water use efficiency. Although the results of this study suggested that replacing 60% of the estimated daily evapotranspiration with SDI is sufficient for maximum corn yields, additional observations will be needed to determine whether corn production with SDI is feasible in the region and to develop recommendations for farmers choosing to adopt the method. Improved weather forecasting and crop coefficient functions developed specifically for the region should also contribute to more efficient irrigation management.

Published by Elsevier B.V.

1. Introduction

The US Department of Agriculture's National Agricultural Statistics Service (NASS) divides the US into 20 water resource areas, with the Lower Mississippi (WRA 08) containing portions of Missouri, Kentucky, Arkansas, Tennessee, Mississippi, and Louisiana. Producers in WRA 08, also called the Mid-South, planted just over 400,000 ha of corn (*Zea mays* L.) for grain or seed in 2003 (USDA-NASS, 2004). However, the recent increased interest in bio-fuels, especially corn-based ethanol, is leading many farmers to consider increasing corn production. Although rainfall in the Mid-South is sufficient in most years to produce a corn crop, University of Arkansas Cooperative Extension Service (UA-CES) does not recommend corn production without irrigation (Tacker et al., 2003).

Timely irrigation of corn has been shown to increase yields (Vories et al., 1993), and irrigation has also been shown to influence other aspects of corn production. Smith and Riley (1992) observed lower levels of corn earworm damage in irrigated plots. They also suggested that a combination of factors including drought stress affect aflatoxin production in field corn. Those factors probably explain why Zuber et al. (1976) and Lillehoj et al. (1983) both observed a higher incidence of aflatoxin in southern US states than northern. Furthermore, lending agencies often require irrigation to protect their investment before making crop production loans in the region. It is not surprising then that the Census of Agriculture reported that approximately 62% of the cropland producing corn for grain or seed in the Mid-South was irrigated in 2003 (USDA-NASS, 2004).

Farmers must irrigate wisely to maximize returns on their substantial irrigation investments. Published UA-CES recommendations for corn provide information concerning irrigation management (Tacker et al., 2003). Use of the Arkansas Irrigation Scheduler (AIS) (Cahoon et al., 1990) is recommended to ensure adequate moisture to satisfy crop needs while avoiding saturated soil conditions that deprive roots of necessary oxygen. The AIS program suggests changing water management in response to

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0378-3774/$ – see front matter. Published by Elsevier B.V.
doi:10.1016/j.agwat.2008.12.004

differences in soil texture. However, soils in the region are quite variable, due to alluvial and sometimes seismic activity. Sadler et al. (2002) observed large differences in corn yield response to sprinkler irrigation both within and across soil mapping units, with large differences observed over relatively short distances.

Corn and other Mid-South crops are primarily surface or center pivot irrigated. Historically, water for irrigation was plentiful and relatively inexpensive, so application efficiency was not a major concern. Recently however, shortages have been observed in the region in both groundwater and surface water supplies and those shortages are predicted to increase. Systems such as low energy precision application (LEPA) (Lyle and Bordovsky, 1981) that have shown water and energy savings in other areas have not been adopted in the region. Furrow diking is a common practice with LEPA due to the high instantaneous water-application rates. However, farmers in the Mid-South are hesitant to install furrow dikes due to concerns about impeding surface drainage following rainfall.

Similarly, some producers in arid areas use subsurface drip irrigation (SDI) for row crops like corn or cotton. In addition, Adamsen (1992) reported that trickle irrigation was as effective as sprinkler irrigation in Virginia and used less water to obtain the same yields. However, growers in the Mid-South have generally felt that the improved efficiencies possible with drip irrigation were not sufficient to offset the relatively high installation cost and maintenance requirements with SDI.

With projections of more water shortages in the region and tighter energy supplies resulting in greater pumping costs, high application efficiencies associated with SDI may be an appropriate way to reduce water use and corresponding production costs for corn production. However, few studies have been conducted with SDI under Mid-South conditions. The objective of this study was to determine the yield response of SDI-irrigated corn in the Mid-South.

2. Methods

Field studies were conducted at the University of Arkansas Northeast Research and Extension Center (NEREC) at Keiser (35°40′N, 90°06′W) during the 2002–2004 growing seasons to investigate the response of corn to different drip irrigation management strategies. The soil in the study area was mixed, with approximately 53% mapped as Convent fine sandy loam (coarse-silty, mixed, superactive, nonacid, thermic fluvaquentic endoaquepts), 26% mapped as Steele loamy sand (sandy over clayey, mixed, superactive, nonacid, thermic aquic udifluvents), and 20% mapped as Sharkey silty clay (very-fine, smectitic, thermic chromic epiaquerts). Additional soils information is included in Table 1. The field was precision graded to approximately 1 mm m^{-1} slope. The crops were produced on beds spaced 97 cm apart.

Table 1
Soil physical properties at study site for corn irrigation study at NEREC, Keiser, Ark. (from Soil Survey Staff, 2008, USDA-NRCS, undated).

Depth (cm)	Clay content (%)	Moist bulk density (g cm^{-3})	Available water (cm cm^{-1})
	Convent fine sandy loam		
0–28	0–18	1.30–1.65	0.18–0.23
28–183	0–18	1.30–1.65	0.20–0.23
	Steele loamy sand		
0–15	5–12	1.40–1.50	0.10–0.12
15–51	5–12	1.40–1.50	0.03–0.10
51–58	15–27	1.45–1.50	0.13–0.16
58–183	35–50	1.50–1.60	0.10–0.15
	Sharkey silty clay		
0–15	40–60	1.20–1.50	0.07–0.14
15–86	60–90	1.20–1.50	0.07–0.14
86–183	25–90	1.20–1.70	0.12–0.22

Table 2
Significant dates for corn irrigation study at NEREC, Keiser, Ark.

Event	Date		
	2002	2003	2004
Preplant nitrogen			
Date	10 April	2 April	25 March
Rate (kg N ha^{-1})	112	112	112
Planting	11 April	3 April	2 April
Sidedress nitrogen			
Date	8 May	16 May	21 May
Rate (kg N ha^{-1})	168	179	254
First irrigation	3 June	1 June	28 May
Final irrigation	4 August	24 July	18 July
Harvest	3 September	27 August	9 September

The study plots were planted in early April each year (Table 2) at approximately 9 seeds m^{-1} (90,000 seeds ha^{-1}). The crops were managed according to UA-CES recommendations for fertility and weed control. Nitrogen (N) was applied in split applications (Table 2), with preplant fertilizer applied as dry urea (46% N) using a broadcast spreader and a liquid mixture of urea and ammonium nitrate (UAN, 32% N) knifed into the soil in sidedress applications in 2002 and 2004. Soft soil conditions from recent rains precluded using the applicator in 2003, so granulated urea (46% N) was applied with a hand spreader when the soil surface dried. Care was taken to keep urea out of the plant whorls and rainfall immediately following the application should have minimized N loss to the atmosphere. The sidedress N rate was increased in 2004 due to plant yellowing associated with excessive spring rain and expected early-season N loss. Phosphorus was included in the preplant application in each year based on UA-CES recommendations.

To accurately control the amount of water applied, SDI tubing with an emitter spacing of 30 cm and emitter flow rate of 1.02 L h^{-1} (TSX 515-12-450, T-Systems Int., San Diego, CA; mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture or the University of Arkansas) was placed under every row at a depth approximately 30 cm below the original (unbedded) soil surface. To reduce the risk of damaging the tubing, minimal tillage was employed. Each year the existing soil beds were reformed; no other tillage operations were used.

The study was designed as a randomized complete block with a split plot arrangement of treatments. The whole plot treatment was irrigation level. Three irrigation levels consisted of replacing approximately 100% of the estimated crop evapotranspiration (ET_c) for a non-stressed crop (HI), replacing approximately 60% of the estimated ET_c for a non-stressed crop (LO), and no irrigation (NI). The split plot treatment was hybrid, with three hybrids of different relative maturities (Pioneer Brand P33J57, 113 days relative maturity; P32P76, 116 days; and P31B13, 119 days). Subplot dimensions were six rows by 15 m, except for the NI plots, which were 12 rows wide to insure against lateral water movement from an adjacent irrigated plot.

During the irrigation period, water was applied daily in the absence of rain based on crop water use estimates from the AIS (Cahoon et al., 1990). The program estimates pan evaporation from maximum daily temperature and day length, and uses a pan coefficient of 0.86 to estimate a grass reference ET (ET_o). The crop coefficient function for corn was adapted from research conducted in North Dakota (Stegman et al., 1977) and ranges from 0.20 to 1.06 as a function of crop age. FAO 56 (Allen et al., 1998) suggests a peak value of 1.2; however, the authors of the AIS elected to go with the lower value (Cahoon et al., 1990).

The surface wetness coefficient in the AIS program, which accounts for greater evaporation following rain or irrigation, was modified for SDI. Since water is applied subsurface, irrigation does not wet the soil and leaves in the same way as surface or sprinkler irrigation. Therefore, the coefficient was still affected by rainfall, but not by irrigation. Application efficiency was assumed to be 100% for the small plots. Rainfall and temperature data collected by NEREC staff for the National Weather Service were used for irrigation scheduling. Irrigations began when the estimated soil water deficit (SWD) reached approximately 50 mm before the tassel stage each year and continued until the starch line was observed approximately half way up the kernels at the center of the cobs. The 50 mm value represents approximately 50% of the total available water in the top 1 m of the Sharkey and Steele soils based on the midpoints of the ranges in Table 1.

Watermark sensors (Irrometer Co., Riverside, CA) were placed approximately 20 cm below the surface of the soil bed, approximately 15 cm above the drip tubing. In 2002, sensors were read daily during the irrigation period at approximately 10:00 AM CDT. In 2003, all sensors were connected to a central datalogger (Campbell Scientific, Logan, UT) and data were collected hourly from the sensors. Soil moisture tension values were calculated using a calibration equation provided by Campbell Scientific for a range of 0–200 kPa. Watermark sensors were not used in 2004.

The number of plants in 3 m of row was determined in two to four locations per plot in May or June of each year. Two center rows were harvested from each plot with a combine equipped with a two-row corn header and modified to weigh grain from small plots. Plots were harvested in late August or early September each year (Table 2). Grain moisture content was measured for each plot and yield was adjusted to 150 g kg^{-1}. The yield associated with irrigation was calculated as the difference between the yield from an irrigated treatment and the yield for the NI treatment in the same replication. Irrigation water use efficiency (IWUE) was calculated as the ratio of the additional yield to total gross irrigation, as suggested by Howell (2000) and others.

All data were analyzed using the Statistical Analysis System (SAS 9.1 for Windows; SAS Institute Inc., Cary, NC), PROC GLM. *F*-Tests were considered significant at the 0.05 level of probability and Fisher's protected least significant difference (LSD) was used to compare treatment means for significant ($p \leq 0.05$) effects.

3. Results and discussion

The 2002 growing season was much drier than the 30-year average, primarily due to an extremely dry April (Table 3). However, 58 mm of rainfall were recorded on the final 2 days of March (248 mm for the month), so there was ample soil water entering April. Similarly, 39 mm of rainfall were recorded on May 1. Less than 60% of the 30-year average rainfall was recorded in July. In 2003, the total rainfall for April–July exceeded the 30-year average even though the April total was less than average (Table 3).

Table 3
Rainfall during the study period and 30-year (1963–1992) mean values for corn irrigation study at NEREC, Keiser, Ark.

Period	Rainfall (mm)			
	2002	2003	2004	30-year mean (1963–1992)
April	4	57	159	127
May	144	289	165	138
June	87	84	67	91
July	51	147	182	88
August	149	17	86	76
Total, 1 April–31 August	434	595	659	520
Planting—first irrigation	144	346	298	–
Irrigation period	138	123	241	–

Table 4
Irrigation applied and estimated evapotranspiration during the study period and yield response for corn irrigation study at NEREC, Keiser, Ark.

Irrigation treatment[a]	2002	2003	2004	3-year mean
	Irrigation period (days)			
	63	54	52	56
	Total seasonal application (mm)			
HI	353	284	199	279
LO	254	189	141	195
NI	17[b]	0	2[b]	6
	Estimated crop evapotranspiration[c] (mm)			
Planting to harvest	704	689	729	707
Irrigation period	444	368	344	385
	Grain yield (Mg ha^{-1} at 150 g kg^{-1} MC)[d]			
HI	12.9a	11.7a	12.2a	12.2a
LO	13.1a	12.3a	12.1a	12.5a
NI	9.7b	11.3a	11.5a	10.8b
	Yield associated with irrigation (Mg ha^{-1})[e]			
HI	3.2	0.3	0.8	1.4
LO	3.4	1.0	0.6	1.7
	Irrigation water use efficiency (kg m^{-3})			
HI	1.0	0.1	0.4	0.5b
LO	1.5	0.5	0.4	0.8a

[a] Irrigation treatments: HI = irrigation replaced 100% of estimated daily water use; LO = irrigation replaced 60%; NI = no irrigation after system flush each year.
[b] All plots received application during system flush each season; 2003 flush before planting.
[c] Estimated from Arkansas Irrigation Scheduler (Cahoon et al., 1990).
[d] Significant year-by-irrigation-treatment interaction. Means in a column followed by the same letter are not significantly different at the 5% level of significance.
[e] Calculated as the difference between the yield from an irrigated treatment and the yield for the NI treatment in the same replication.

In 2004, the total was also greater than the 30-year average, with only the June total less than average (Table 3).

Uniform plant populations were observed each year, ranging from 59,000 plants ha^{-1} in 2003 to 72,000 plants ha^{-1} in 2004. The year-to-year differences probably resulted from differences in seed quality (germination) and the timing and amount of rainfall between planting and emergence. The crops developed at a normal pace each year, and even though the rainfall patterns differed, the first irrigation was made approximately 1 June each year (Table 2). The total irrigation water applied each year is shown in Table 4. In 2002 and 2004, water was applied to the NI plots during irrigation system maintenance at the beginning of the irrigation period. In 2002 extensive flushing was required after repairs to the system; however, 25 mm of rainfall were recorded on the day following the system flush, reducing any effect of the irrigation. In 2003 the system maintenance was conducted prior to planting. The most irrigation water was applied in 2002, the year with the least rainfall during the April–August growing season (Table 3). However, total rainfall during the irrigation period was least in 2003, when the irrigation period was 9 days shorter than in 2002. The least irrigation water was applied in 2004, the year with the most rainfall during the growing season and the most during the irrigation period.

The ET_c during the irrigation period estimated by the AIS (Cahoon et al., 1990) was highest in 2002, the year with the greatest irrigation application, and least in 2004, the year with the least irrigation application (Table 4). Such a response was expected, since ET_c was considered when scheduling the irrigations. However, ET_c is not easily estimated with a high degree of accuracy. Vories and Tacker (2006) reported that ET_o values calculated with the AIS for Keiser, Ark. were consistently higher than values calculated with the standardized Penman-Monteith equation (ASCE-EWRI, 2004).

Table 5
Comparison of estimated ET_o values from different estimation methods for corn irrigation study at NEREC, Keiser, Ark.

Method	Estimated ET_o (mm)			
	2002	2003	2004	3-year mean
	Planting to harvest			
Arkansas Irrigation Scheduler[a]	918	882	940	913
Observed pan evaporation[b]	914	870	1019	934
Standardized Penman-Monteith[c]	736	746	792	758
	Irrigation period			
Arkansas Irrigation Scheduler	442	359	345	382
Observed pan evaporation	411	338	337	362
Standardized Penman-Monteith	335	298	276	303

[a] (Cahoon et al., 1990) from temperature data collected by NEREC staff for the National Weather Service.
[b] From the National Climatic Data Center (NOAA, undated) using the pan coefficient in the AIS (0.86).
[c] (ASCE-EWRI, 2004) with the program PMday (PMday, 2006), calculated from weather data obtained from an electronic weather station.

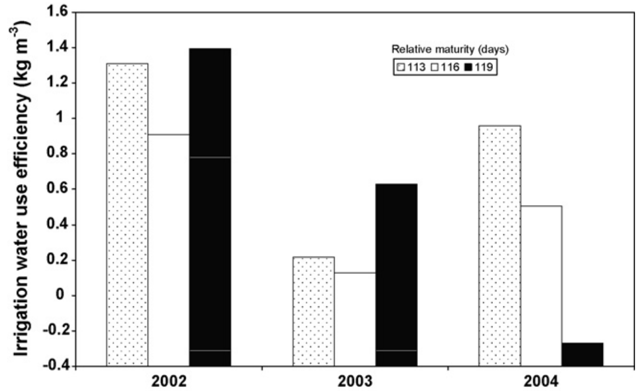

Fig. 1. Irrigation water use efficiency for corn irrigation study at NEREC, Keiser, Ark., during the 2002–2004 growing seasons (values shown are averages of two irrigated treatments).

Table 5 compares ET_o values for the study period using different calculation methods. Since the AIS estimates pan evaporation, there was relatively good agreement with observed pan evaporation from the National Climatic Data Center (NOAA, undated) using the pan coefficient used in the AIS (0.86). However, both were higher than the values calculated using the standardized Penman-Monteith equation (ASCE-EWRI, 2004) with the Excel (Excel 2003 SP3; Microsoft Corporation, Redmond, WA) spreadsheet program PMday (PMday, 2006). The Penman-Monteith values were calculated from weather data obtained from an electronic weather station (Campbell Scientific, Inc.). Few Arkansas farmers have access to detailed weather data; however, future updates of the AIS will include the option to input ET_o directly for those users wishing to do so.

Furthermore, better crop coefficient functions are needed for the Mid-South. As mentioned previously, the function in the AIS was adapted from a function developed in North Dakota. Lysimeter-based functions have not been developed in the region. Recently, weighing lysimeters have been installed by the US Department of Agriculture's Agricultural Research Service (ARS) in Stoneville, Miss. (Fisher, 2004) and by Louisiana State University in Saint Joseph, La. (Clawson and Hendrix, 2007). Both systems have been used to study cotton ET_c, but will likely be available for other crops in the future. Similarly, photographic techniques being developed (Purcell, 2000; Trout and Johnson, 2007) may result in simpler methods for developing crop coefficients than using weighing lysimeters. Until better functions are developed, irrigators in the Mid-South must rely on published values and experimental data from other regions.

Although the three-year means indicate significantly lower yields for the NI treatment, a significant year-by-irrigation-treatment interaction was observed (Table 4). No significant differences were observed among the irrigation treatments in either 2003 or 2004. A large difference was observed in 2002, the year with the least rainfall during the growing season, but no difference was detected between the two irrigated treatments (HI and LO) in any year.

The inconsistent response observed in this study is similar to the findings of Lamm et al. (1995). They observed a significant reduction in three-year-average corn yields in Kansas between treatments replacing 100% and 75% of ET; however, the difference was not significant in 2 of the 3 years. A 50% of ET treatment yielded significantly less in all three years.

There was significantly more yield associated with irrigation in 2002, the year with the least rainfall during the growing season (Table 4). However, as with total grain yield, there was no significant difference between the two irrigated treatments.

In calculating the IWUE, the water applied to the NI plots during system maintenance (Table 4) was subtracted from the total gross irrigation for the irrigated treatments. Since there was no significant yield difference between the two irrigated treatments, the treatment with the lower water application (LO) had the higher IWUE (Table 4). IWUE was numerically highest in 2002, the year with the least rainfall during the growing season, but the year effect was not statistically significant. There was a significant year-by-hybrid interaction, but no obvious trends were observed (Fig. 1). Differences among the hybrids were only significant in 2004, when the value for the latest maturing variety (P31B13) was negative ($-0.3\ kg\ m^{-3}$).

The IWUE values from this study were lower than many of the values reported in the literature, even in 2002. Howell et al. (1989) observed a similar value for fully sprinkler irrigated corn ($1.4\ kg\ m^{-3}$), but most studies reported higher values for the more efficient treatments (e.g., Musick and Dusek, 1980; Caldwell et al., 1994; Howell et al., 1995; Lyle and Bordovsky, 1995). However, those studies were conducted in more arid locations.

The low IWUE values observed in 2003 and 2004 highlight a problem with irrigation scheduling in the Mid-South. The inability to accurately predict the timing and amount of rainfall results in irrigation applications that turn out to have been unnecessary or even deleterious when they exacerbate waterlogging of the soil. Improvements in weather forecasting may help with the problem, but unpredictability of the weather is a well-known characteristic of the region.

The differences in water status between the NI and the two irrigated treatments are indicated by the average soil moisture

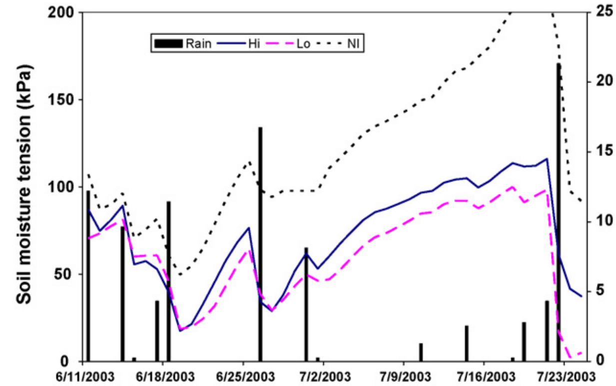

Fig. 2. Average soil moisture tension values from Watermark sensors for corn irrigation study at NEREC, Keiser, Ark., during 2003 irrigation period.

tension readings from the Watermark sensors from 10:00 AM CDT daily in 2003 (Fig. 2). Each point in the figure is the average of 12 values (3 hybrids $\times$ 4 reps). However, readings from the individual sensors were quite variable (data not included). Even though the sensors were placed approximately 15 cm above the drip tubing, the readings were probably highly influenced by the proximity of the sensor to an emitter. It was not possible to infer any differences in the water status between the two irrigated treatments due to the variability in the readings.

Even though 2002 was a drier growing season than the 30-year average, the driest month was April, when evaporative demand was low. Although the results of this study suggested that replacing 60% of the estimated daily ET_c with subsurface drip irrigation is sufficient for maximum corn yields, there were no extended drought periods during the growing seasons of any of the three years of the study. July rainfall in 2 of the 3 years (2003, 2004) greatly exceeded the 30-year average and July is typically the time of maximum irrigation for corn in the region. Additional observations will be needed to determine whether corn production with SDI is feasible in the region and to develop recommendations for farmers choosing to adopt the method.

4. Conclusion

The results of this study suggest that replacing 60% of the estimated daily crop ET with subsurface drip irrigation is sufficient for maximum corn yields. However, there were no extended drought periods during the growing seasons for any of the three years of the study. July rainfall in 2 of the 3 years (2003, 2004) greatly exceeded the 30-year average and July is typically the time of maximum irrigation for corn in the region. Additional observations will be needed to determine whether corn production with SDI is feasible in the region and to develop recommendations for farmers choosing to adopt the method. Furthermore, improved weather forecasting and crop coefficient functions developed specifically for the region should result in more efficient irrigation management.

Acknowledgement

Funding for these studies was provided by the Arkansas Corn and Grain Sorghum Promotion Board.

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